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# Comparing Physical and Cyber-Enhanced Product Dissection: Analysis from Multiple Perspectives*

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*Product dissection has evolved into a versatile pedagogical platform useful across the engineering curriculum. Simulation technologies have recently broadened the opportunities to implement cyber-enabled product dissection, but its effectiveness on achieving educational outcomes must first be studied. In this paper, we carefully delineate the difference between physical, virtual, and cyber-enhanced (a blend of physical and virtual) dissection considering the advantages and limitations of each type of platform. We then study and report on the impact of variations of cyber-enhanced dissection across two populations of sophomore engineering students at two universities using a number of exercises and data collection methods. We found that students perceived the cyber-enhanced dissection exercises to be relevant to the students' own professional preparation, to facilitate easier dissemination, to better align with emerging industrial practices, and to provide unique experiences not available in other courses the students had taken. Some potential drawbacks of cyber-enhanced dissection were also reported by students, including technology distracting them from the core educational objectives and over-reliance on historical data of unknown origin. Although there are important tradeoffs between physical and cyber-enhanced dissection that need to be considered, using a blend of physical and virtual instructional tools may provide an effective platform to teach a wide range of engineering concepts across a curriculum.*

**Keywords:** product design; product dissection; digital tools; cyber-enhanced dissection; student perceptions

## 1. INTRODUCTION

ABOUT TWO DECADES have passed since undergraduate engineering education in the United States came under fire from government, industry and engineering societies [1–5]. The Accreditation Board for Engineering and Technology (ABET) reacted by outlining technical and non-technical skills necessary for engineers to succeed in the modern workplace [6]. Engineering education leaders called for instructional methods that seemed practical and attainable yet varied from conventional, instructor-centered methods [7, 8]. One of the major issues raised during this period involved the incorporation and teaching of engineering design in the university curriculum [9, 10]. In the midst of this, product dissection was introduced and has become an increasingly popular pedagogical practice used to address product design.

### *1.1 Product dissection as a means to teach engineering design*

Product dissection can trace its roots back to Sheppard's *Mechanical Dissection* course, which was initiated in 1990 for freshmen and sophomore engineering students at Stanford [11–13]. Since then product dissection has become a popular approach for teaching a number of diverse subjects across an engineering curriculum using active, hands-on experiences. Physical dissection has been used to help students identify relationships between fundamental engineering concepts and the related hardware design [14]. The basic physical dissection platform has been extended to include virtual components in the context of an introduction to design and manufacturing course to teach component names, their functions, and their manufacturing methods [15].

Product dissection, and related reverse engineering, have been incorporated across the curricular landscape for students ranging from freshmen to seniors [16] as well as in graduate courses to improve student understanding of platform commonality through product family design research [17]. The terms product dissection and reverse engineering

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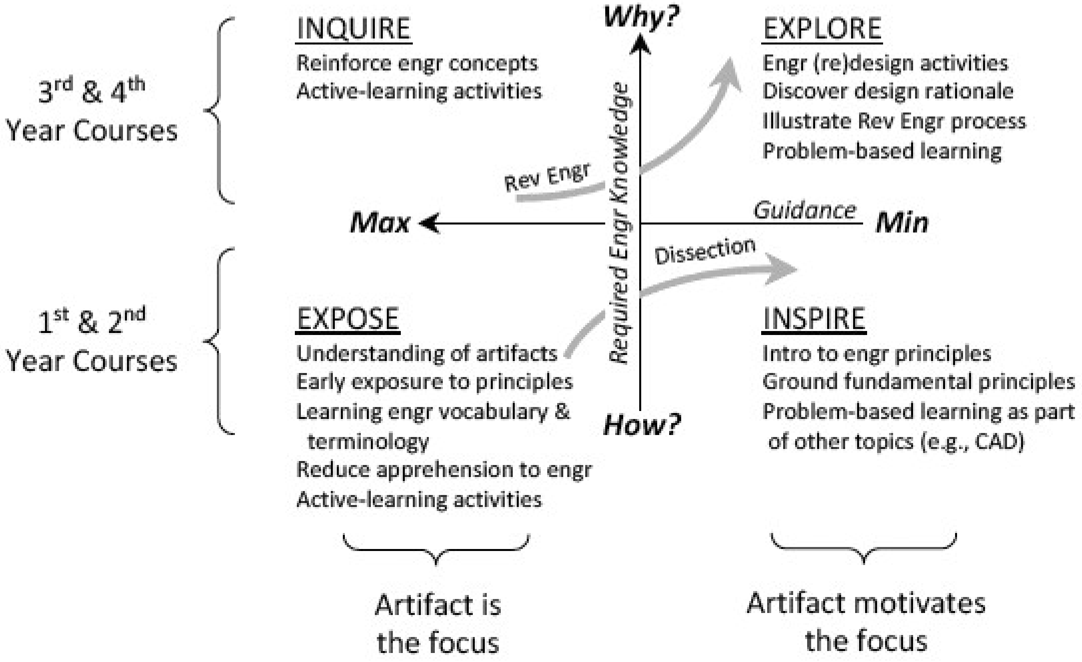


Fig. 1. Framework for Engineering Dissection Activities [22].

have been used interchangeably in both engineering education literature and course titles [e.g., 13, 18–21]. Recent work [22] has helped unravel the two related, yet distinct, ideas by proposing a Dissassemble/Analyze/Assemble (DAA) framework that clarifies why and how these two distinctly different ideas should be classified. This framework identifies DAA activities as product dissection if they are "hands-on" activities to couple engineering principles with significant visual feedback [23]. In contrast, DAA reverse engineering activities initiate "the redesign process wherein a product is predicted, observed and disassembled, analyzed, tested, 'experienced', and documented in terms of functionality, form, physical principles, manufacturability, and assemblability" [24, p. 226].

According to the Framework for Engineering Dissection Activities proposed in [22], product dissection and reverse engineering should be used for four complementary purposes: to expose, inspire, inquire, and explore (see Fig. 1). The delineation into four categories is helpful in guiding the appropriate placement of these types of dissection and reverse engineering activities into the design curriculum. For example, product dissection activities work well to *expose* and *inspire* students and are suitable for freshmen and sophomore level courses respectively. Reverse engineering activities fall under the *inquire* and *explore* categories of the DAA framework and are thus best suited for junior and senior level course integration. For this paper, we focus on the use of product dissection in lower level courses and study the impact of emerging cyber-technologies on the student perceptions and learning in dissection-centric courses.

### *1.2 Cyber-enhanced dissection*

Despite numerous benefits of physical dissection, there are a number of drawbacks [25, 26]. Acquiring and maintaining products and tools for dissection can be very costly, ranging from $500/year for a 50-person class to $5000/year for a 1200-person class. Also, the workspace and storage necessary may be prohibitive. Despite these and other associated reasons, cyber-enhanced dissection is beginning to gain some traction in engineering education.

Using a simulated digital environment to supplement traditional instruction is not a new concept. Early attempts to understand the role of digital environments in workplace instruction demonstrated the potential of computer simulations acting as a cognitive apprentice [27]. The use of virtual laboratory environments to replace or supplement physical experiments in engineering education emerged soon after that. Virtual laboratory experiments were created to supplement the physical laboratories to teach various electronics and circuitry concepts [28]. Both quantitative and qualitative results strongly supported the use of the virtual experiments as a supplemental source of learning. In [29], a virtual laboratory was created to provide students with more and quicker access to feedback on the thermodynamic performance of their virtual and simulated design concepts. Studies across three universities demonstrated potential to provide valuable additional instruction to students using the virtual simulations. Other simulated environments have been developed to enhance or replace the traditional physical instruction of a number of engineering topics including nuclear magnetic resonance spectroscopy [30], unit operations [31], system dynamics [32], ultra-precision machining [33], and strength of materials [34]. Recently, digital technologies have been explored to supplement traditional dissection activities [15]. In this paper, we present a multi-university implementation and assessment of cyber-enhanced dissection instruction across two courses.

Cyber-enhanced dissection, while still limited to simple human-computer interfaces such as keyboards and mice, has enormous potential to augment or even replace physical dissection just as virtual surgery tools and practices have been used to supplement or supplant a number of surgical procedures [35, 36]. Virtual dissection could provide similar realism to physical dissection at a fraction of the operating costs while also enhancing the teaching of cyber-enabled tools. Although using haptic devices with true interactivity is perhaps the next step to move from cyber-enhanced to true virtual dissection, current work focuses on simpler interfaces and their effectiveness compared to physical dissection. Note that the terminology virtual dissection is often used for what is actually cyber-enhanced dissection (a hybrid that takes advantage of cyberinsfrastructure to enhance physical dissection). The authors purposely make a distinction between the two, and this paper presents a study that compares cyber-enhanced dissection to physical dissection.

While the associated educational strategies and relative effectiveness are still being developed and studied, there would seem to be a synthesis between cyber-enhanced dissection and the social culture of today's engineering students. The current generation of engineering students is defined by the digital culture they create and in which they live [37]. Most new undergraduate students are younger than the microcomputer and are used to constant connectivity [38]. Beyond cell phones, email, wikis, blogs, and video sharing websites like YouTube, social networking websites such as Facebook, Bebo, and MySpace have created a new archetype for communication and collaboration within this generation, cultivating a culture of digital communities [39, 40]. Moreover, even scholarly literature is now accessed through on-line archival resources like Google Scholar. While most students are familiar with the use of digital tools for everyday applications, it is natural to wonder if educators and researchers in the engineering fields can and should capitalize on the digital community's social network paradigms, and emerging multimodal literacies to facilitate pedagogical goals. This represents a legitimate motivation behind cyber-enhanced dissection to engage students within a culture they are already embracing as part of their lives in order to increase the effectiveness of engineering education.

The next generation of scientists and engineers is going to be entering a global knowledge economy, largely driven by digital technologies, tools, protocols, and processes. However, knowledge webs that allow access to experts, archival resources, shared investigations, computer simulations and authentic environments, do not automatically expand a person's knowledge. The availability and accessibility of information does not intrinsically create an internal ideational framework that can be used to interpret reality [41]. Success in this knowledge economy will not only require a familiarity with the use of cyber-enabled applications like design repositories to solve problems, but an understanding of how cyber-enabled resources can be combined to create a framework that supports innovative product design. In fact, a recent Blue-Ribbon report on cyberinfrastructure from the US National Science Foundation called for engineering educators to prepare tomorrow's engineers to function "across disciplines, cultures, and institutions using technology-mediated collaborative tools" [42, p. 26].

Foreseeing this shift in engineering education, research, and practice, the digital tools necessary to support the design of detailed components are presented [18]. These tools collectively support the emerging fully digital processes of component layout, modeling, analysis, simulation, prototyping, and documentation, allowing for integration with other cyber-enabled product realization tools. Previous efforts to develop and integrate some of these tools have focused on the implementation of multimedia and cyber-enabled tools for product dissection education and research [e.g. 43–45]. Semantic models have been developed to capture and re-use product and manufacturing information in the context of reverse engineering processes [46]. Three-dimensional CAD representations of product components from dissection processes have been captured in databases to aid freshmen in their understanding of the engineering discipline [23].

Building upon these foundational efforts aimed at providing digital resources to support product dissection as a means to teach engineering design, a team of educators from multiple universities developed CIBER-U (Cyber-infrastructure-based engineering repositories for undergraduates) [25, 26]. In CIBER-U, digital repositories and Wiki-Media resources provide a shared set of resources for students across universities, programs, academic years, and semesters. Some of the technical foundations and recent education initiatives involving the CIBER-U developments can be found in related work [47–49]. Other universities are now part of the CIBER-U consortium and as a result of the expansion, additional innovative educational applications using the digital resources have been developed, including video podcasts [50], modules for middle school students [51], dissection modules for experiential engineering education [52], and cyber-enhanced dissection [15]. While previous work has introduced these digital resources, in this paper we study student perceptions as to the effectiveness of the digital tools and technology at two universities.

## 2. BACKGROUND AND SETTING

Across the US many universities have implemented product dissection in their curricula [53]. More recently, as a part of a US National Science Foundation funded nine-university collaborative project, two sophomore engineering courses, one at a large research university in the Northeast United States and another at a science and engineering university in the Midwest United States, have employed physical product dissection activities that were supported through cyberinfrastructure. In both courses students were part of product design teams that disassembled a product, investigated various design and manufacturing issues associated with the project, and then reassembled the product. These are standard product design learning activities. In line with Fig. 1, both courses had the goal of inspiring students by using product dissection to introduce effective design practice and emerging design tools, grounding this experience in a student-centered, problem-based environment. In both courses students worked in groups on physical dissection projects. Students also had access to cyber tools, including wiki pages, text about the dissection process accompanied by pictures, CAD diagrams, CAD assembly files and disassembly videos, which they were given and allowed to access as they desired. Hence, these experiences have been labeled as cyber-enhanced dissection projects.

### *2.1 Motivation for the study*

The motivation for this study comes from the underlying, yet often untested, assumption that cyber-tools and cyber-supported learning are beneficial. The pedagogical rationale for employing digital tools to enhance or replace traditional learning methods has not been transparent [44], yet such a shift in instructional tools should be a data-driven decision. As should be expected, within the scientific community there is a push to explore and exploit new cyber-technologies. A recent search yielded 74 funding opportunities from the US National Science Foundation that mention the term cyberinfrastructure. Even outside the scientific community, others [54, 55] are starting to raise issues related to how we consider, interact with, and educate a more digitally literate generation, composed of young adults often referred to as digital natives [55]. As technology impacts our society, it also impacts industry, but what role should these technological changes play in engineering education? Various recent efforts [e.g., 56–60] across the engineering education landscape suggest that a growing number of diverse multimedia tools have been or will soon be incorporated into engineering education efforts. It is dangerous to assume that incorporation of any pedagogical practice or educational tool is necessarily beneficial just because it capitalizes on the latest technology.

As digital natives, engineering students do not benefit from simple exposure to cyber-tools; educational benefits only occur if cyber infrastructure does indeed enhance their educational experiences. This study looks to serve as a catalyst to start a data-driven discussion on the use and impact of cyber tools in engineering education to enhance instruction within a particular context-specific environment, in this case product dissection.

While studies related to distance laboratory learning exist [e.g., 61–64], they have mostly been conducted from a solely academic perspective and have contrasted traditional education with remote distance learning. This study, however, wishes to consider a hybrid educational environment that employs in-person instruction enhanced by a complementary cyber infrastructure.

## 3. METHODOLOGY

While not pretending to be comprehensive, this initial effort looks to understand the impact, in terms of perceptions of utility, on engineering students when cyber tools are used to enhance instruction within the particular context of product dissection.

### *3.1 Guiding research questions*

The research study was designed as a scientific inquiry that neutrally considered student perceptions of the advantages and disadvantages of two related pedagogical practices without pre-conceived assumptions. The overarching research questions that drove this study include the following.

- Do engineering students perceive differences between engaging in either physical vs. cyber-enhanced dissection?
- What advantages and disadvantages do engineering students identify when comparing physical vs. cyber-enhanced dissection?

### *3.2 Populations studied*

Two purposely diverse populations of engineering students were studied. All students involved in the study were enrolled in one of two sophomore-level design courses taught at different universities during the same academic semester (fall 2008). Both course instructors had used physical dissection activities before, and each implemented both physical and cyber-enhanced dissection activities in their classrooms at the time of the study. The study did not attempt to alter the instructors' in-place practices but was designed around them.

One course was conducted by a male, full professor at a large Research I university in the northeastern United States (NEU). This NEU course typically has a population of close to 200 students and includes both a large lecture component and a laboratory component. The laboratory component is where the students perform their group dissection projects, which include a series of questions and issues to consider pre-dissection, during dissection, during reassembly, and after reassembly. In the semester of the study, 166 students were enrolled, of whom 75% were sophomores.

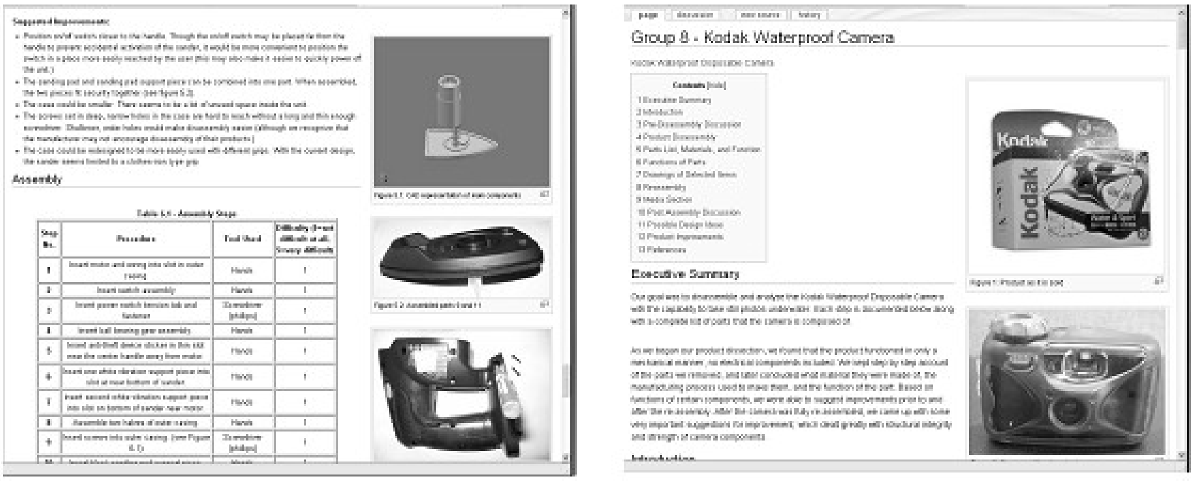
The other course was conducted by a female, assistant professor at a midsize Research II university in the Midwestern United States (MWU) during the same semester as the NEU course. MWU is a predominantly technological university with the majority of its student body majoring in engineering. Her sophomore-level course usually has a population of about 25 students and is conducted in a combined lecture/laboratory block format in a computer-equipped laboratory. This particular semester, 23 students (all sophomores) were enrolled. Students in this course experience two dissection projects; the first is a physical dissection and the second is a cyber-enhanced dissection. At NEU, the students were all mechanical and aerospace majors, while at MWU the students were interdisciplinary engineering majors without a single focus area.

In the NEU class, all students were grouped in teams. Each team engaged in one physical dissection activity, for which all members had access to cyber tools that supported the project. The activity was completed in a laboratory outside class with the instructor present to facilitate over a period of nine weeks. The NEU teams each performed physical dissections of different products such as disposable cameras, staplers, routers, screwguns, belt sanders, reciprocating saws, jig saws, and angle grinders. The accessible cyber tools included wiki pages, text about the dissection process accompanied by pictures, CAD diagrams, CAD assembly files and disassembly videos. Typical student use of the cyber-tools included viewing these various representations of disassembled products and parts to better inform their disassembly, analysis, and reassembly tasks. Examples of the materials stored and created by the groups are shown in Fig. 2.

The NEU instructor allowed students to choose to participate in either dissections that required the use of cyber tools or in dissections that did not require the use of cyber tools but for which cyber tools were available. About half (52%) of the students in the NEU class chose to participate in dissections that required the use of cyber tools (NEU cyber-required groups) and were subsequently placed in groups where they were asked to develop digital dissection support tools, such as creating linked wiki reports with uploaded product pictures, assembly animations, and disassembly/assembly videos. The NEU cyber-required student groups were required to submit their project reports using MediaWiki and were provided with a corresponding report template [65]. These students were also expected to upload their associated product information into the accompanying repository formats. The digital group reports, among other educational resources can be found at the wiki site [66].

Those students who opted for the physical dissection only were placed in groups with access to the cyber tools, but they were not required to use any of them (NEU cyber-option groups). The NEU cyber-option groups had access to the wiki pages, but did not have their own group page and could not edit anything on the site; they were expected to submit a traditional hard copy project report as opposed to a digital report. All student groups presented their findings in class.

The MWU course was conducted in a different format; each student first participated in a physical dissection. Next, each student engaged in a cyber-enhanced product dissection activity. Both dissections occurred in an extended three-hour class period with instructor facilitation. For the cyber-enhanced dissection, students were divided into teams of two to three with each team dissecting a different brand of easy touch, heavy-duty stapler. (Although the staplers were different, each had the same functionality.) The groups worked in a location with computer access to the same cyber tools


Assembly

Group 8 - Kodak Waterproof Camera

Executive Summary

Sample Wiki page for Ryobi Palm Sander

Sample Wiki page for Kodak Waterproof Camera

Fig. 2. Sample wiki materials

as the cyber-option groups at NEU had. This allowed each group to study multiple product designs while only physically dissecting a single product. Typical student use of the cyber tools included viewing the disassembled parts of a product, i.e. the inner workings of a stapler, before dissecting the stapler. The digital resources facilitated student engagement in a scientific approach to the disassembly. The MWU students did not post their results online; they, like NEU's cyber-option group, only used the online information to guide their dissection.

### *3.3 Data collection*

Various sources, leveraging common collection instruments in product design education, were used to collect data for the study. When possible, similar data-collection instruments were administered to NEU and MWU students. Qualitative and quantitative data were gathered via surveys with open-ended and Likert scale items that addressed issues related to product design, the use of product dissection as an educational tool, and the role that cyber tools should play in product dissection. At NEU, the surveys were administered in the first week of class and the final week of class, at the same time as instructor evaluations were administered. At MWU, the surveys were administered only in the final week of class. Additional student data were also collected, compiled, and analyzed through focus group interviews conducted by the instructor. These group interviews were recorded with notes taken by the instructor and written answers to the questions posed provided by the group members themselves. All data from both NEU and MWU were subsequently compiled and analyzed by an external evaluator and her research assistant.

### *3.4 Data analysis*

The subsequent section on findings highlights the statistical methods used to interpret the quantitative data. In most instances descriptive statistics or 2-tailed t-tests (either independent samples t-tests or paired samples t-tests, when analyzing pretest and posttest data) were employed. To control for multiple comparisons in t-test analyses, a post hoc Bonferroni correction was administered to avoid cumulative Type I error [67].

For the qualitative analysis, an inductive analytical framework was employed that was committed to three general flows of activities: reducing the data, creating thematic categories, and drawing conclusions [68] through a data analysis spiral [69]. The external evaluator initially combed through the open-ended survey items and focus group interview transcriptions to reduce the mass of student data to thematic categories that presented themselves with regularity. The external evaluator coded the data according to descriptive regularities [70] and then began to consider cross comparisons between the qualitative and quantitative data collected for the two groups of students (from NEU and MWU) in the study, and between the study findings and the scholarly findings from the existing literature base.

### *3.5 Limitation of study*

The study of existing instructional practices impacted both the study design and the instruments for data collection that were implemented in this research. The NEU instructor incorporated self-selection rather than random selection to treatments. By allowing both the NEU cyber-required and cyber-option groups access to the cyber tools, the study was able to compare variations of cyber-enhanced product dissection but not able to compare cyber-enhanced dissection to physical dissection. The tradeoff for the aforementioned limitations to the study is that this body of research provides realistic insight on actual engineering education practices and their effectiveness.

## 4. RESULTS AND DISCUSSION

In this section, the results from the NEU and MWU implementations are presented and relevant insights are discussed. The first subsection focuses on the impact of the cyber-enhanced class experience on a number of learning perceptions and software tool usage.

### *4.1 Impact of cyber-enhanced experience for students*

Table 1 shows the pretest and posttest items given to the students in the NEU class. Each of the items started with the same phrase with a slight variation between the pretest and posttest. The pretest was worded "Until now, my classes in engineering have . . ." while the posttest was worded "This class has . . ." Each item used a Likert scale with 1 representing strongly disagree and 5 representing strongly agree. The sample size varied by item due to missing or illegible data, but at least 114 paired scores were for available for each item. Significance for a nondirectional (2-tailed) test is shown using asterisks in the table below. In order to ensure an experimentwise error rate of less than either .05 or .01, a post hoc Bonferroni correction factor was applied resulting in adjusted *p*-values of .002 and .0005, respectively. Since the pretest data acted as the control for the study, the effect size was calculated by taking the ratio of the difference in the pretest and posttest means to the standard deviation of the pretest mean.

While still lecture-oriented (item a), without significant change in active student participation during the course meeting time (item i) the NEU students felt that the course, with its cyber-enhanced product dissection project, was different than other engineering courses they had taken. Table 1 shows that no significant differences were found for items (items s, t, and u) that were unrelated to course goals associated with product

Table 1. NEU student perception pretest and posttest response means

| **Until now, my classes in engineering have . . . (Pretest)**<br>**This class has . . . (Posttest)**<br>**n = 117 (unless otherwise noted)** | **Pretest Mean (SD)** | **Posttest Mean (SD)** | **p-value** | **Effect Size** |
|---|---|---|---|---|
| a. been lecture-oriented | 4.111 (0.879) | 4.214 (0.869) | 0.3388 | 0.115 |
| b. allowed for me opportunities to collaborate with other students [d] ** | 3.356 (0.957) | 3.915 (0.939) | 0.0000 | 0.585 |
| c. exposed me to genuine engineering problems [c] * | 3.207 (1.009) | 3.629 (0.947) | 0.0007 | 0.419 |
| d. allowed for hands-on learning experiences [b] ** | 2.730 (1.046) | 3.330 (1.114) | 0.0000 | 0.574 |
| e. prepared me for the workplace [a] * | 2.746 (0.967) | 3.158 (1.001) | 0.0018 | 0.426 |
| f. given me opportunities to meet and learn from practicing engineers [d] ** | 2.686 (1.068) | 3.288 (1.125) | 0.0000 | 0.564 |
| g. allowed me to use the types of technology and facilities that are used by engineers in today's workforce [c] * | 2.828 (1.174) | 3.284 (1.125) | 0.0017 | 0.389 |
| h. offered me a chance to identify and formulate engineering problems* | 3.111 (1.024) | 3.530 (1.023) | 0.0009 | 0.403 |
| i. provided opportunities for active student learning | 3.607 (0.871) | 3.726 (0.887) | 0.2820 | 0.131 |
| j. made use of problems and situations similar to those that I expect to face in the workplace | 3.111 (1.024) | 3.239 (1.023) | 0.3459 | 0.124 |
| k. presented new ideas and material in an authentic context [b] | 3.500 (.850) | 3.741 (.915) | 0.0374 | 0.284 |
| l. helped me be more familiar with what a practicing engineer does | 3.410 (1.018) | 3.709 (0.965) | 0.0362 | 0.294 |
| m. given me opportunities to design and conduct experiments in engineering, as well as to analyze and interpret engineering data** | 2.855 (1.116) | 3.376 (1.040) | 0.0003 | 0.467 |
| n. helped me learn how to communicate more effectively [d] | 3.483 (1.036) | 3.788 (1.037) | 0.0221 | 0.295 |
| o. given me opportunities to function as a part of a team * | 3.624 (1.006) | 4.060 (0.994) | 0.0010 | 0.433 |
| p. given me opportunities to use modern engineering tools [c] * | 2.991 (1.131) | 3.440 (1.098) | 0.0009 | 0.397 |
| q. given me opportunities to solve problems that have multiple solutions, some of which are better than others [d] | 3.398 (1.103) | 3.771 (0.991) | 0.0073 | 0.338 |
| r. provided me with opportunities to use creative thinking skills [d] | 3.585 (1.096) | 3.932 (0.976) | 0.0125 | 0.317 |
| s. helped me better understand the role that engineers play in society | 3.778 (0.911) | 3.880 (0.984) | 0.4122 | 0.120 |
| t. provided me with an idea of current issues in the engineering workplace | 3.615 (1.033) | 3.641 (1.021) | 0.8483 | 0.025 |
| u. helped me understand the professional and ethical responsibility of engineers [d] | 3.898 (0.990) | 3.907 (1.078) | 0.9424 | 0.009 |

[a] n = 114 paired scores, [b] n = 115 cyber-required responses, [c] n = 116 cyber-required responses, [d] n = 118 cyber-required responses
Significance indicated as follows: * $p < .05$, ** $p < .01$

dissection or the use of cyber-tools. The smallest *p*-values and the largest effect sizes tended to correlate with items related to collaboration (items b and o); hands-on experiences (item d); exposure to problems, tools, technology, and practitioners of engineering (items c, f, g, h, p); as well as opportunities to engage in identification, experimental design, and analysis of engineering problems (items h and m).

Table 2 shows the mean growth from the pretest to posttest items, as was done in Table 1, but separated by the student-selected treatment to work in either a cyber-required or cyber-option group. The sample sizes varied by item due to missing and illegible data; all n values are found in Table 2. An independent two-sample t-test, was used to denote significant differences between the two treatment groups. The independent t-tests allowed for equal variances and unequal sample sizes, as was the case for items a and m, and allowed for unequal variances (and either equal or unequal sample sizes) for all other items. Since "growth" could have been negative, a 2-tailed test was used. As growth is reported, no effect sizes can be calculated.

In order to ensure an experimentwise error rate of less than .05, a Bonferroni correction was applied resulting in adjusted *p*-values of .002. When the cyber-required and cyber-option groups were compared, there were no statistically significant differences in the students' perceptions of the course. Of interest is the difference in the gains between the cyber-required and cyber-option groups for the item "allowed me to use the types of technology and facilities that are used by engineers in today's workforce" (item g). Although not statistically significant under the Bonferroni correction, one of the greatest differences was between the two groups with the greater gain for the cyber-option rather than the cyber-required group, as one might have expected. It could be theorized that this is because the cyber-option group found less benefit in using the digital tools they already knew how to use.

Table 3 shows the means and standard deviations of NEU and MWU responses to posttest items related to the specific use of digital tools made available through cyber infrastructure to the students. All the items ranged from 0 (signifying a response of either not at all or never) to 5 (signifying an extremely positive or frequent response). The number of responses varied per item (as denoted in Table 3) due to missing or illegible data. For NEU, no significant differences were found in the responses of the cyber-required (CR) and cyber-option (CO) groups; however, some significant differences (using a 2-tailed independent sample t-test that allowed for unequal variances and unequal sample sizes with a post hoc Bonferroni correction) were noted between MWU and these two groups. In order to ensure an experimentwise error rate of less than .05, .01, or .001, a Bonferroni correction was applied resulting in adjusted *p*-values of .004, .0008, and .00008 respectively. When the cyber-required and cyber-option groups were compared, there were no

Table 2. Mean response growth for NEU class sorted by student-selected treatment

| **Until now, my classes in engineering have . . . (Pretest) This class has . . . (Posttest)** | **Cyber-Required Students' Growth Mean (SD) n = 57** | **Cyber-Option Students' Growth Mean (SD) n = 55** | ***p*-value** |
|---|---|---|---|
| a. been lecture-oriented | 0.250[b] (0.977) | 0.000 (1.305) | 0.255 |
| b. allowed for me opportunities to collaborate with other students | 0.404 (1.510) | 0.727 (1.297) | 0.224 |
| c. exposed me to genuine engineering problems | 0.357[b] (1.341) | 0.527 (1.303) | 0.499 |
| d. allowed for hands-on learning experiences | 0.278[a] (1.522) | 0.891 (1.301) | 0.025 |
| e. prepared me for the workplace | 0.111[a] (1.423) | 0.685[d] (1.315) | 0.030 |
| f. given me opportunities to meet/learn from practicing engineers | 0.333 (1.585) | 0.836 (1.488) | 0.085 |
| g. allowed me to use the types of technology and facilities that are used by engineers in today's workforce | 0.228 (1.615) | 0.804[d] (1.396) | 0.098 |
| h. offered me a chance to identify and formulate engineering problems | 0.351 (1.369) | 0.426[d] (1.354) | 0.772 |
| i. provided opportunities for active student learning | 0.123 (1.166) | 0.056[d] (1.235) | 0.769 |
| j. made use of problems and situations similar to those that I expect to face in the workplace | 0.246 (1.455) | 0.000[d] (1.517) | 0.386 |
| k. presented new ideas and material in an authentic context | 0.263 (1.330) | 0.189[c] (1.161) | 0.754 |
| l. helped me be more familiar with what a practicing engineer does | 0.298 (1.488) | 0.204[d] (1.606) | 0.748 |
| m. given me opportunities to design and conduct experiments in engineering, as well as to analyze and interpret engineering data | 0.509 (1.311) | 0.389[d] (1.709) | 0.678 |
| n. helped me learn how to communicate more effectively | 0.404 (1.348) | 0.255[d] (1.566) | 0.591 |
| o. given me opportunities to function as a part of a team | 0.386 (1.544) | 0.473 (1.289) | 0.747 |
| p. given me opportunities to use modern engineering tools | 0.386 (1.461) | 0.463 (1.370) | 0.775 |
| q. given me opportunities to solve problems that have multiple solutions, some of which are better than others | 0.404 (1.486) | 0.309 (1.477) | 0.736 |
| r. provided me with opportunities to use creative thinking skills | 0.421 (1.511) | 0.291 (1.462) | 0.644 |
| s. helped me better understand the role that engineers play in society | 0.161[b] (1.372) | -0.018 (1.354) | 0.490 |
| t. provided me with an idea of current issues in the engineering workplace | -0.018 (1.541) | 0.000[d] (1.387) | 0.950 |
| u. helped me understand the professional and ethical responsibility of engineers | -0.053 (1.381) | 0.036 (1.201) | 0.716 |

[a] n = 54 cyber-required responses, [b] n = 56 cyber-required responses, [c] n = 53 cyber-option responses, [d] n = 54 cyber-option responses

statistically significant differences in the students' perceptions of the course.

Although for items 4–12, all but one mean is larger for the cyber-option (CO) group compared to the cyber-required (CR) group. Table 3 data show there were no significant differences in the two NEU groups' reported use of the repository tools. This was true for both design and communication tools. Tables 1, 2, and 3 suggest that the flexible course structure allowed students to self-select the level of cyber-enhancement that would be most beneficial. Table 3 also suggests that the NEU students were more likely to make use of the manufacturing process data, as well as several of the communication cyber-tools, than the MWU students.

### *4.2 Comparison of cyber-enhanced experiences*

Students at NEU worked on the product dissection projects in groups outside the class lecture meeting time. Students at MWU worked on the cyber-enhanced product dissection project in groups following a physical dissection only project; both of which occurred during their extended class periods. While not surprising considering the difference in class structure, Table 3 indicates that NEU students used the communication tools more than did the MWU students with statistically significant differences in the use of group e-mail lists. Table 3 also suggests that both sets of students used the digital tools to help them generate and eliminate ideas for their projects in much the same way, but MWU students were found to use the specific design tools in the repository less than did the NEU students. There were statistically significant differences in the perceived usefulness of the manufacturing process data between both NEU groups and the MWU students and the perceived usefulness of the 3D assembly animations between the cyber-option NEU students and the MWU students. These findings are consistent with the focus group data which mirrored the differences in instructional objectives for the two courses. The MWU course emphasized physical dissections; therefore the MWU students found the 3D assembly animations more useful than the manufacturing process data.

Focus groups of students were used at MWU to obtain feedback from students on their use of the cyber-tools. The cyber-tools reported by the groups as being used most frequently were the artifact search, the list of components, and the morphological matrix. The artifact list and component list refer to the listing of parts of the consumer products recorded in the repository. Other comments from the groups showed that the product information provided in the repository did help some students eliminate parts they could

Table 3. Digital tool item comparison between MWU and each of the NEU groups of students

| **Survey Item** | **Cyber-required NEU Mean (SD) n = 67** | **Cyber-option NEU Mean (SD) n = 55** | **MWU Mean (SD) n = 18** | ***p*-value** | |
|---|---|---|---|---|---|
| | | | | **CR & MWU** | **CO & MWU** |
| 1. How clear was the goal of having the design repositories for your project? | 2.563 (1.283) [a] | 2.782 (1.257) | 3.444 (0.984) | .003* | .026 |
| 2. To what extent was the product information provided in the design repositories useful in helping you *generate* new ideas? | 2.621 (1.187) [b] | 2.607 (1.201) [f] | 2.167 (0.985) | .107 | .126 |
| 3. To what extent was the product information provided in the design repositories useful in helping you *eliminate* new ideas? | 2.385 (1.085) [b] | 2.439 (1.118) [e] | 2.176 (1.334) [g] | .557 | .468 |
| Rate how useful you found each of the tools in the design repositories: | | | | | |
| 4. CAD Models | 3.119 (1.409) | 3.400 (1.435) | 2.611 (1.195) | .134 | .027 |
| 5. 3D assembly animations | 3.164 (1.431) | 3.455 (1.425) | 2.235 (1.033) [g] | .004 | .000* |
| 6. Material property data | 3.075 (1.318) | 3.182 (1.234) | 2.222 (1.114) | .009 | .004 |
| 7. Manufacturing process data | 3.134 (1.325) | 3.345 (1.364) | 1.889 (0.900) | .000*** | .000*** |
| Rate how frequently you used each of the following communication cyber-tools when working on your group's design project: | | | | | |
| 8. Shared team folders | 2.104 (1.468) | 2.214 (1.486) [d] | 1.333 (0.594) | .000** | .000** |
| 9. Group email lists | 3.672 (1.408) | 3.768 (1.561) [d] | 1.333 (0.686) | .000*** | .000*** |
| 10. Wiki entries | 2.403 (1.338) | 2.804 (1.656) [d] | 2.056 (1.162) | .285 | .039 |
| 11. Versioning software | 1.864 (1.226) [b] | 1.778 (1.093) [c] | 1.333 (0.594) | .011 | .032 |
| 12. Message boards | 1.955 (1.440) | 2.232 (1.651) [d] | 1.167 (0.383) | .000** | .000*** |

[a] n = 64 cyber-required responses, [b] n = 66 cyber-required responses, [c] n = 55 cyber-option responses, [d] n = 56 cyber-option responses, [e] n = 57 cyber-option responses, [f] n = 58 cyber-option responses, [g] n = 17 MWU responses
Significance indicated as follows: * $p < .05$, ** $p < .01$, *** $p < .001$

not use, but most students felt that this information did not help them generate new ideas or eliminate options. The groups felt they better understood how to work with design repositories and cyber-tools, but the repositories were used most frequently to get pictures of the product citing that the repositories needed better compatibility, more products, and a website that was easier to navigate.

Data were also obtained from the MWU focus groups to determine student perceptions as to the advantages and disadvantages of cyber-enhanced dissection. Students cited advantages of cyber-enhanced dissection as being safer, being neater, allowing detailed 3-D views of parts, always having enough dissection materials for each student and not having to worry about breaking the product. They reported the disadvantages were not knowing the true size of the product's parts, not having every single part and its function available, and not getting to put the product back together.

### *4.3 Student comparison of cyber-enhanced and physical dissection*

Table 4 summarizes the survey and frequency responses to open-ended items that asked students to evaluate the physical as opposed to cyber-enhanced dissection experiences. When an individual addressed multiple issues, each issue was tallied in the appropriate category. Note that multiple rephrasings of the same idea by the same individual were only counted as a single response in that category. The table is arranged so that each column represents the advantage of one type of dissection, either physical or cyber-enhanced. The data in the table combine the responses from NEU and MWU classes since all had the same general trends in the most frequent citations for advantages and disadvantages. The exceptions for categories in which NEU students made a response, but no MWU students did, are denoted in the table with an asterisk (*).

With the exception of the first listing, all advantages of cyber-enhanced dissection were considered in reference to physical dissection. Some of the advantages of physical dissection could also be considered as advantages of cyber-enhanced dissections (since both allow for hands-on interactions with the product); however, others were in direct contrast to cyber-enhanced dissection and are denoted with a cross (†) in Table 4.

Open-ended data from NEU as well as open-ended and focus group data from MWU yielded consistent feedback that the main benefit of a physical dissection is the kinesthetic experience. Many, but not all, of the advantages of physical dissection could also be considered advantages of cyber-enhanced dissections since, as frequently worded by the students, cyber-enhanced dissections give you the "best of both worlds." The students cited multiple benefits of a cyber-enhanced dissection, which were quite varied in nature and in direct contrast to physical dissection. These benefits ranged from providing a safer dissection experience to saving time, money, and

Table 4. Frequency table of student perceptions of advantages of physical and cyber-enhanced dissections.

| **Advantages of physical dissection** | **Number of responses** | **Advantages of cyber-enhanced dissection** | **Number of responses** |
|---|---|---|---|
| Hands-on interaction with product, tactile feedback, use of senses | 62 | "Best of both worlds", able to benefit from cyber-tools and physical experience | 28 |
| No need to learn cyber-tools, not distracted by cyber-tools, no computer access problems | 22† | Less chance for broken/lost/inoperable parts | 20 |
| Learn to use tools, manual skills needed for disassembly; no way to replicate the difficulty to take things apart | 18 | Not as messy/dirty, more organized | 17 |
| Able to see things, can visualize 3D components better, hard to visualize things virtually | 16 | Convenient easy access to product/parts, can repeat dissection anytime/anywhere | 15* |
| More interesting/engaging/fun | 9* | Easy access to part information & product research (component details, view object from many angles, exploded views, etc.) | 15 |
| Get hands-on experience you need that will be used on the job; more like industry | 9 | Able to use digital technologies as used in industry | 14 |
| People remember more/learn better when they actually do rather than when they read or see | 8* | Less time consuming than physical dissection | 13 |
| Requires verbal communication, improves oral and written communication skills, more team reliance/interaction | 8† | Cheaper, cost savings, errors not as costly | 12 |
| Must rely on your own/group members' ideas because you don't have access to others' ideas | 7† | Better/easier dissemination of ideas, easier communication between/within groups | 11 |
| More problem solving needed to avoid mistakes, must be more cautious/observant to avoid mistakes | 5† | Learn from/access to others' work/ideas, compare your ideas to others' | 11 |
| Get to study components and discuss their use | 4 | Safer than physical dissection | 10 |
| Allows for mistakes to happen which is useful; must be more cautious and observant to avoid mistakes, helps you learn to handle mistakes | 3*† | Easier/more efficient documentation, easier to organize/record process | 9 |
| Helps to understand the size of the components | 3 | Access to product use as well as disassembly and reassembly animations and videos | 8* |
| Don't need to rely on what could be erroneous information | 2† | Easier, less work | 7 |
| | | Provides more guidance and reinforcement than physical only dissection | 7 |
| | | No need for tools, need for fewer tools | 5 |
| | | Multiple people can watch at same time, work on project at the same time | 5* |
| | | Easy to modify, update, tweak submissions | 4 |

* Cited by NEU students only, † Represents an advantage of physical over cyber-enhanced dissection

wear and tear on the dissected product. Students also acknowledged that the cyber-enhanced dissection provided additional resources, better dissemination of ideas, and experience with digital technologies used by industry. Some students preferred the physical dissection over cyber-enhanced dissection because they liked the challenge of doing the dissection without reliance on (possibly faulty) posted information and where they were forced to rely on their own groupmates' ideas or to learn from their own and their groupmates' mistakes. Others mentioned they preferred physical dissection over cyber-enhanced dissection since the use of cyber tools or need for technology posed a distraction from the main goal of product dissection.

As noted in Table 4, some advantages were mentioned only by NEU students, but not by MWU students. Of those, the most frequent was the accessibility of cyber-enhanced dissection. The NEU students who were required to work on this project outside the class period appreciated that the cyber tools afforded individuals time to revisit those sections of the repository of interest repeatedly at their own pace.

## 5. CONCLUSIONS

While many in engineering education use the term virtual dissection to mean many things, cyber-enhanced dissection is a more appropriate term when the hands-on aspect of product dissection is present. Moreover, students can engage in cyber-enhanced dissections at many different levels and with a diverse array of cyber tools. Within this study there were at least three such levels of participation (NEU cyber-required, NEU cyber-option, MWU cyber-enhanced in class dissection), yet all students found product dissection to be beneficial.

This work highlights the need to use precise language in engineering education, since "reverse engineering" and even "cyber-enhanced product dissection" can mean very different things to different people. The study focuses on three related cyber-enhanced activities and highlights the myriad of ways that instructors use similar physical dissection activities with varying expectations as to the level of cyber enhancement. More importantly, this study provides valuable insight into the student perceptions of cyber-enhanced, physical dissection activities and their reported usage of cyber-tools. As digital simulation and modeling tools continue to supplement traditional instruction, it is important for engineering educators to consider the value of these tools on pedagogical objectives. While students typically embrace technology in their social lives, they need to be able to see clear instructional benefit from cyber-enhanced instructional technologies. These results help inform engineering educators about student perceptions of both physical dissection, in general, and cyber-enhanced physical dissection, in particular.

It is not correct to assume that students view cyber-enhanced dissection as superior to physical dissection since there seem to be tradeoffs involved in the use of each. In light of the advantages and disadvantages cited by the students, engineering educators need to evaluate which type of dissection best fits their instructional needs and their course goals.

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## REFERENCES

1. D. T. Curry, Engineering schools under fire, *Machine Design*, **63**(20), 1991, pp. 50–54.
2. C. Fincher, Trends and issues in curricular development in higher education, *Handbook of Theory and Research*, (ed. J. Smart), Agathon, New York (1986) pp. 275–308.
3. J. H. McMasters and S. D. Ford, An industry view of enhancing design education, *Journal of Engineering Education*, **79**(3), 1990, pp. 526-29.
4. L. M. Nicolai, Designing a better engineer, *Aerospace America*, **30**(4), 1992, pp. 30-33.
5. L. M. Nicolai, Viewpoint: An industry view of engineering design education, *International Journal of Engineering Education*, **14**(1), (1998) pp. 7–13.
6. ABET Engineering Accreditation Commission, *Engineering Criteria 2000: Criteria for accrediting programs in engineering in the United States*, Accreditation Board for Engineering and Technology (ABET), Inc., Baltimore, MD. 1997.
7. R. M. Felder, D. R. Woods, J. E. Stice, and A. Rugaracia, The future of engineering II. Teaching methods that work, *Chemical Engineering Education*, **34**(1), 2000, pp. 26–39.
8. A. Rugaracia, R. M. Felder, J. E. Stice, and D. R. Woods, The future of engineering education: A new vision for a new century, *Chem. Eng. Ed.*, **34**(1), 2000, pp. 16–25.
9. M. R. Emami, Teaching engineering design: A hybrid framework, *Proceedings of the Second Canadian* Design *Engineering Network International Conference on Design Education, Innovation, and Practice*. Alberta, Canada, 2005.
10. S. Sheppard and R. Jenison, Freshman engineering design experiences: An organizational framework, *Int. J. Eng. Educ.*, **13**(3), 1997, pp. 190–197.
11. S. D. Sheppard, Mechanical dissection: An experience in how things work, *Proceedings of the Engineering Education: Curriculum Innovation and Integration*, Santa Barbara, CA, 1992.
12. S. D. Sheppard, Dissection as a learning tool, *Proceedings of the Frontiers in Education Conference,* Nashville, TN, 1992.
13. A. M. Agogino, S. D. Sheppard, and A. Oladipupo, Making connections to engineering during the first two year, *Proceedings of the Frontiers in Education Conference*, Nashville, TN, 1992.
14. M. Brereton, S. Sheppard, and L. Leifer, Students connecting engineering fundamentals and hardware design: Observations and implications for the design of curriculum and assessment methods, *Journal of Engineering and Applied Science*, **2**, 1995, pp. 950–56.
15. A. F. McKenna, W. Chen, and T.W. Simpson, Exploring the impact of virtual and physical dissection activities on students' understanding of engineering design principles, *Proceedings of the American Society of Mechanical Engineers International Design Engineering Technical Conferences & Computers and Information in Engineering Conference*, Brooklyn, NY, 2008, DETC2008-49783.
16. K. N. Otto, and K. L. Wood, Product evolution: A reverse engineering and redesign methodology, *Research in Engineering Design*, **10**(4), 1998, pp. 226–243.
17. T. W. Simpson, and H. J. Thevenot, Using product dissection to integrate product family design research into the classroom and improve students' understanding of platform commonality, *International Journal of Engineering Education*, **23**(1), 2007, pp. 120–30.
18. R. E. Barr, T. J. Krueger, and T. A. Aanstoos, The new digital engineering design and graphics process, *Engineering Design Graphics Journal*, **66**(3), 2002, pp. 6–11.
19. J. Burton and D. White, Selecting a model for freshman engineering design, *Journal of Engineering Education,* **88**(3), 1999, pp. 327–32.
20. C. Dym, A. Agogino, O. Eris, D. Frey, and L. Leifer, Engineering design thinking, teaching and learning, *Journal of Engineering Education,* **94**(1), 2005, pp. 103–20.
21. K. L. Wood, D. Jensen, Bezdek, and K. N. Otto, Reverse engineering and redesign: Courses to incrementally and systematically teach design, *Journal of Engineering Education*, **90**(3), 2001, pp. 363–74.

22. M. M. Ogot, G. E. Okudan, T. W. Simpson, and J. S. Lamancusa, A framework for classifying disassemble/analyze/assemble activities in engineering design education, *Journal of Design Research*, 7(2), 2008, pp. 120-35.
23. R. E. Barr, P. S. Schmidt, T. J. Krueger, and C. Y. Twu, An introduction to engineering through an integrated reverse engineering and design graphics project, *Journal of Engineering Education*, **89**(4), 2000, pp. 413–17.
24. K. N. Otto, and K. L. Wood, Product evolution: A reverse engineering and redesign methodology, *Journal of Research in Engineering Design*, **10**(4), 1998, pp. 226–43.
25. M. Devendorf, K. E. Lewis, T. Simpson, R. Stone, and W. Regli, Evaluating the use of digital repositories to enhance product dissection activities in the classroom, *J. of Computing and Information Sci. in Eng.*, **9**(4), 2009, http://link.aip.org/link/?CIS/9/041008 (accessed 26 November 2009).
26. T. W. Simpson, K. E. Lewis, R. B. Stone, and W. C. Regli, Using cyberinfrastructure to enhance product dissection in the classroom, *Proceedings of the Industrial Engineering Research Conference*. Nashville, TN, 2007.
27. S. Lajoie and A. Lesgold, Apprenticeship training in the workplace: Computer-coached practice environment as a new form of apprenticeship, *Intelligent Instruction by Computer: Theory and Practice*, (eds. M. J. Farr and J. Psotka), Taylor and Francis, New York, 1992, pp. 15–36.
28. P. J. Mosterman, M. A. M. Dorlandy, J. O. Campbell, C. Burow, R. Bouw, A. J. Brodersen, J. R. Bourne, Virtual engineering laboratories: Design and experiments, *Journal of Engineering Education,* **83**(3), 1994, pp. 279–285.
29. J. Baher, Articulate virtual labs in thermodynamics education: A multiple case study, *Journal of Engineering Education*, **88**(4), 1999, pp. 429–434.
30. M. C. Dorneich and P. M. Jones, The UIUC virtual spectrometer: A java-based collaborative learning environment, *Journal of Engineering Education*, **90**(4), 2001, pp. 713–720.
31. T. F. Wiesner and W. Lan, Comparison of student learning in physical and simulated unit operations experiments, *Journal of Engineering Education*, **93**(3), 2004, pp. 195–204.
32. P. Mandal, K. K. Wong, and P. E. D. Love, Internet-supported flexible learning environment for teaching system dynamics to engineering students, *Computer Applications in Engineering Education,* **8**(1), 2000, pp. 1–10.
33. W. B. Lee, J. G. Li, and C. F. Cheung, Development of a virtual training workshop in ultra-precision machining, *International Journal of Engineering Education*, **18**(5), 2002, pp. 584–596.
34. L. R. Chevalier, J. N. Craddock, P. C. Riley, and B. J. Trunk, Interactive multimedia labware for strength of materials laboratory, *Computer Applications in Engineering Education*, **8**(1), 2000, pp. 31–37.
35. J. Marescaux and F. Rubino, Telesurgery, telementoring, virtual surgery, and telerobotics, *Current Urology Reports*, **4**(2), 2003, pp. 109–13.
36. P. Blyth, I. Anderson, and N. Stott, Virtual reality simulators in orthopedic surgery: What do the surgeons think? *Journal of Surgical Research*, **131**(1), 2006, pp. 133–39.
37. J. Cohan, For teens, MySpace.com is just so last year, *The Wichita Eagle*, May 8, 2006, http://www.redorbit.com/news/technology/494845/myspacecom_is_just_so_last_year/index.html (accessed 12 December 2008).
38. D. G. Oblinger, C. A. Barone, and B. L. Hawkins, *Distributed education and its challenges: An overview*, American Council on Education, Washington, DC, 2001.
39. S. Hansell, For MySpace, making friends was easy. Big profit is tougher, *New York Times*, April 23, 2006. http://www.nytimes.com/2006/04/23/business/yourmoney/23myspace.html (accessed 13 December 2008).
40. C. Wilson, MySpace invitation opens a whole new world, *USA Today*, May 14, 2006, http://www.usatoday.com/life/columnist/finalword/2006-05-09-final-word_x.htm (accessed 12 December 2009).
41. C. J. Dede, The evolution of distance education: Emerging technologies and distributed learning, *American Journal of Distance Education,* **10**(2), 1996, pp. 4–36.
42. D. E. Atkins, K. K. Droegemeier, S. I. Feldman, H. Garcia-Molina, M. L. Klein, D. G. Messerschmitt, P. Messina, J. P. Ostriker, and M. H. Wright, *Revolutionizing science and engineering through cyberinfrastructure*: *Report of the National Science Foundation Blue-Ribbon Advisory Panel on Cyberinfrastructure,* National Science Foundation, Arlington, VA. 2003.
43. S. Hsi and A. M. Agogino, The impact and instructional benefit of using multimedia case studies to teach engineering design, *Journal of Educational Hypermedia and Multimedia*, **3**(3/4), 1994, pp. 351–76.
44. B. Masi, The impact of faculty-mentored versus web-guided engineering design experience on freshman skills, *Proceedings of the American Society for Engineering Education Annual Conference and Exposition*, Nashville, TN, 2003.
45. M. Regan and S. Sheppard, Interactive multimedia courseware and the hands-on learning experience: An assessment, *Journal of Engineering Education*, , **85**(2), 1996, pp. 123–31.
46. V. Borja, J. A. Harding, and R. Bell, A conceptual view of data-model driven reverse engineering, *International Journal of Production Research,* **39**(4), 2001, pp. 667–87.
47. R. Stone and K. Grantham-Lough, Using a reverse engineering approach to teach broader engineering design methods, *Proceedings of the Industrial Engineering Research Conference*, Nashville, TN, 2007.
48. M. J. Grauer, I. K. Howley, J. B. Kopena, and W. C. Regli, Towards a format registry for engineering data, *Proceedings of the American Society of Mechanical Engineers International Design Engineering Technical Conferences & Computers and Information in Engineering Conference*, Las Vegas, NV, 2007, DETC2007-35652.
49. K. Grantham-Lough, and R. Stone. Enabling probabilistic risk assessment instruction during the conceptual design phase: Function based risk analysis, *Proceedings of the American Society for Engineering Education Annual Conference and Exposition*, Honolulu, HI, 2007, AC2007-2705.

50. S. B. Shooter, Reverse engineering to design forward: An introduction to engineering experiential education module with video podcasts, *Proceedings of the American Society for Engineering Education Annual Conference and Exposition*, Pittsburgh, PA, 2008, AC2008-1170.
51. T. West, A. Feuerstein, and S. Shooter, Using cyber-infrastructure enhanced product dissection to introduce engineering to middle school students, *Proceedings of the American Society for Engineering Education Annual Conference and Exposition*, Pittsburgh, PA, 2008, AC2008-590.
52. S. B. Shooter, Reverse engineering to design forward: An introduction to engineering experiential education module, *Proceedings of the Industrial Engineering Research Conference*, Nashville, TN, 2007.
53. J. Wood, M. Campbell, K. Wood, and D. Jensen, Enhancing the teaching of machine design by creating a basic hands-on environment with mechanical 'breadboards', *International Journal of Mechanical Engineering Education,* **33**(1), 2005, pp. 1–25.
54. D. G. Oblinger and J. L. Oblinger, *Educating the Net Generation*, Educause, Boulder, CA. 2005.
55. J. Palfrey and U. Gasser. *Born Digital: Understanding The First Generation of Digital Natives*, Perseus, New York. 2008.
56. E. E. Anderson and J. Hashemi, Virtual laboratories: Changing engineering education, *Proceedings of the International Conference on Engineering Education*, San Juan, PR, 2006.
57. A. Dollár, P. S. Steif, and R. Strader, Enhancing traditional classroom instruction with web-based statics course, *Proceedings of the Frontiers in Education Conference*, Milwaukee, WI, 2007.
58. J. I. Messner, S. C. M. Yerrapathruni, A. J. Baratta, and V. E. Whisker, Using virtual reality to improve construction engineering education, *Proceedings of the American Society for Engineering Education Annual Conference and Exposition*, Nashville, TN, 2003.
59. N. Shyansundar and R. Gadh, Internet-based collaborative product design with assembly features and virtual design spaces, *Computer-Aided Design,* **33**(9), 2001, pp. 637–51.
60. M. Wu, J. H. She, G. X. Zeng, and Y. Ohyama, Internet-based teaching and experiment system for control engineering course, *IEEE Transactions on Industrial Electronics,* **55**(6), 2008, pp. 2386–2396.
61. T. M. Abdel-Salam, P.J. Kauffmann, and G.R. Crossman. Are distance laboratories effective tools for technology education? *American Journal of Distance Education,* **21**(2), 2007, pp. 77–91.
62. D. Alexander and R. S. Smelser, Delivering an engineering laboratory course using the Internet, the post office, and a campus visit, *Journal of Engineering Education*, **92**(1), 2003, pp. 79–84.
63. P. Herder, E. Subrahmanian, S. Talukdar, A. Turk, and A. Westerburg, The use of video-taped lectures and web-based communications in teaching: A distance-teaching and cross-Atlantic collaboration, *European Journal of Engineering Education*, **27**(1), 2002, pp. 39–48.
64. M. Ogot, G. S. Elliott, and N. Glumac, An assessment of in-person and remotely operated laboratories, *Journal of Engineering Education*, **92**(1), 2003, pp. 57–63.
65. Template for UB MAE 277 Class, Retrieved 27 April 2010 from http://gicl.cs.drexel.edu/wiki/Template_for_UB_MAE_277_Class.
66. CIBER-U, Retrieved 27 December 2010 from http://gicl.cs.drexel.edu/wiki/CIBER-U.
67. G. A. Morgan and O. V. Griego, *Easy Use and Interpretation of SPSS for Windows,* Lawrence Erlbaum, Mahwah, NJ. 1998.
68. M. B. Miles, and A. M. Huberman, *Qualitative Data Analysis: A Sourcebook of New Methods*, Sage, Beverly Hills, CA. 1984.
69. J. W. Creswell, *Qualitative Inquiry and Research Design: Choosing Among Five Research Traditions*, Sage, Thousand Oaks, CA. 1998.
70. B. G. Glaser and A.L. Strauss, *The Discovery of Grounded Theory*, Aldine, Chicago, IL. 1967.

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